

Available online at www.sciencedirect.com**ScienceDirect**

Procedia Engineering 120 (2015) 1245 – 1248

**Procedia
Engineering**www.elsevier.com/locate/procedia

EUROSENSORS 2015

Dynamic characterization of a transient surface temperature sensor

M.Y. Doghmane, F. Lanzetta*, E. Gavignet

*Institut FEMTO-ST, Département ENERGIE, Université Bourgogne Franche-Comté,
Parc technologique 2 avenue Jean Moulin, 90000 Belfort, France*

Abstract

This paper presents a dynamic characterization setup to calibrate transient surface temperature sensor in radiative conditions. The temperature sensor is a K type (Chromel/Alumel) wire microthermocouple which hot junction is obtained from a layer deposition by PVD process. Three different metallic layers are used (Tungsten, gold and chromium) with two thin film thicknesses (0.4 μm and 0.8 μm). The aim of this work is to develop a dynamic characterization with a radiation source from a laser focused onto the thermocouple's hot junction. The dynamic performance of the sensor is obtained by measuring its unit-impulse response function (Yag laser) and its periodic response under a chopped continuous laser beam (Argon laser). Experiments are realized at atmospheric pressure. The best results are obtained with deposited probes with gold junction of 0.4 μm thickness. The rise-time and decrease-time are equal to 10 μs and 80 μs respectively (Yag laser).

© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015

Keywords: Thermocouple, thin film, surface temperature measurement, dynamic characterization

1. Introduction

Many industrial and engineering applications need the measurement of surface temperature variations under fast heat flux excitation (automotive engines, ebullition, quenching, thermal characterization). These measurements involve sensors with low thermal inertia and fast response time in order to determine the surface temperature and the heat transfer rates between the fluid and the wall [1-3]. The thermocouple we designed and characterized is based on a K type thermocouple. The two wires (Chromel/Alumel) with a 25.4 μm diameter are inserted in a ceramic double bore tube with 20 mm length and 1.2 mm external diameter to constitute the thermocouple (Fig. 1). These thermocouple wires are cut and covered by a cement layer in order to fix the wires. The probe is then heated and smoothed down to obtain a slightly corrugated surface for the junction metallic deposit.

* Corresponding author. Tel.: +33-3-8457-8224; fax: +33-3-8457-8200

E-mail address: francois.lanzetta@univ-fcomte.fr

A thin film is deposited on the ceramic cement by Physical Vapour Deposition (PVD) process to create the hot junction of the thermocouple. The film thickness leads to layers with a very fast response time and a high spatial resolution. Different materials may be employed in the deposit: tungsten (W), gold (Au) and chromium (Cr). Each of these metallic materials is deposit with two layer thicknesses, 0.4 μm and 0.8 μm respectively.

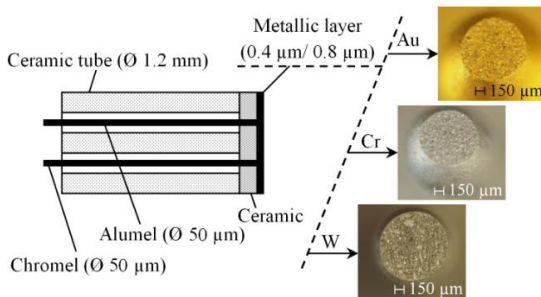


Fig. 1. Thermocouple design with three thin films hot junctions (Au: Gold; Cr: Chromium; W: tungsten)

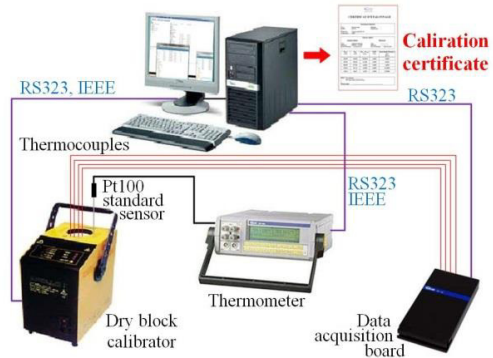


Fig. 2. Static calibration setup.

2. Thermocouple characterization

2.1. Static calibration

The static response is not presented in this work [4] but the probes were placed in a regulated oven within the range [30-300°C] (Fig. 2), the measured temperatures were compared with a precision thermometer (Pt100 platinum resistance). We made a correction equation and a calibration certificate was established for each realized thermocouple. The total resistance of the probes (thin film, wire and ceramic substrate) varies from 30 to 160 Ω and presents a Seebeck coefficient of 40 $\mu\text{V}/^\circ\text{C}$ at 20°C.

2.2. Dynamic characterization with a radiative method

The experimental characterization of the sensors consists in the determination of their temporal and frequency characteristics (response time, constant time, cut-off frequency and phase shift of signals) for different types of radiative excitations in non-stationary regimes. Figure 3 presents the experimental setup for the radiation test bench based on two methods of excitations, continuous excitation and pulsed excitation respectively. The setup integrates a laser system, an optical lens and a data acquisition system. The radiative continuous excitation is made from an argon laser (Spectra Physics Model: Stabilities 2017) which emits wavelength of 473 nm radiation. The beam passes through the acousto-optical modulator which creates radiative heat flux slots modulated sine or square. The average power of the modulated beam (36 mW) is measured by power meter, the focusing lens is used to focus the beam on the junction of the probe. In the case of radiative pulsed excitation, the sensor is excited by a single laser pulse with duration of 15 ns and an energy of 0.65 mJ produced by a Yag laser (wavelength: 532 nm). The goal is to check the sensor sensitivity to a very brief excitation of the order of a nano seconds. The instantaneous power delivered by the Yag laser is about 43 kW. The diameter of the focal is 2 mm, which allows a good distribution of the power pulse on the surface of the probe. Tests are released (in atmospheric pressure and temperature conditions) with different modulation frequencies from 0.2 Hz to 2 kHz in continuous excitation and up to 15 Hz in pulsed excitation.

The measured signal is registered with the data acquisition system operating at 30000 points/sec in continuous mode and at the maximum sample rate (200 kHz) in pulsed mode.

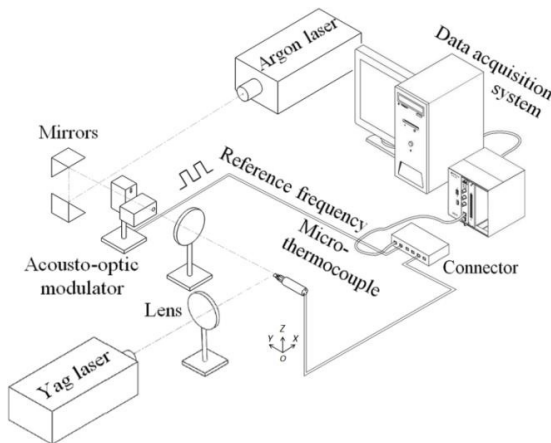


Fig. 3. Radiative dynamic calibration setup.

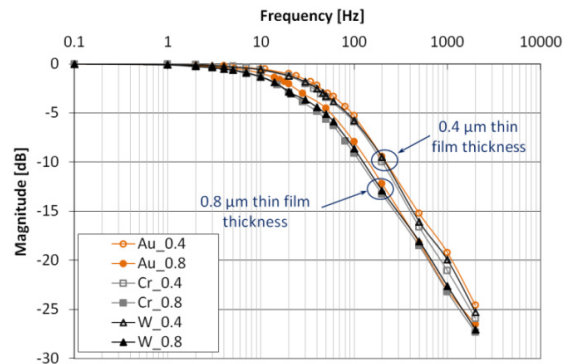
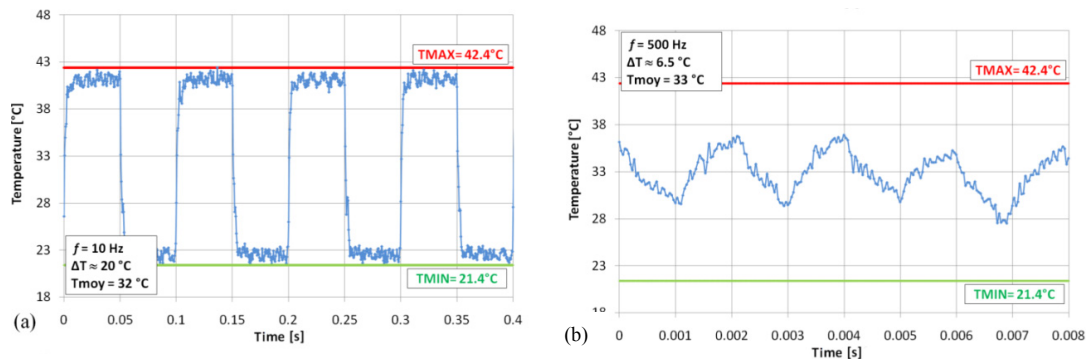
Fig. 4. Frequency response for the two 0.4 μm and 0.8 μm thin film thicknesses (Argon laser).

Figure 4 gives the frequency response for the two 0.4 μm and 0.8 μm thin film thicknesses under Argon laser excitation. The cut-off frequency varies from 28 Hz to 50 Hz respectively. The curves show that the higher cut-off frequencies correspond to the thermocouple with low deposited junction thickness (0.4 μm thickness) whatever is the material, the thermal inertia is less important. These frequencies vary from 20 Hz to 30 Hz for a thickness junction of 0.8 μm and can reach a maximum of about 50 Hz in the case of gold junction of 0.4 μm thickness. The observed slopes have values of -15 dB/decade confirming that the system order is different from the first one which is characterized by respective values of -20 dB/decade.

Fig. 5. Periodic response of the 0.8 μm tungsten thin film (Argon laser)

(a) 10 Hz (b) 500 Hz

Figure 5 describes the amplitude attenuation of a tungsten 0.8 μm thin film thickness. The microthermocouple is excited by a square form laser beam generated by an Argon laser and controlled by the acousto-optic modulator. The tests were conducted for different excitation frequencies (from 0.1 Hz to 2 kHz) at ambient pressure and temperature condition and for a sampling rate of 30 kscan/sec. We observe that duration of temperature increasing phases are similar than the decreasing phases. The measured peak-to-peak amplitude decreases naturally with the frequency to 6.5 $^{\circ}\text{C}$ at 500 Hz. We can also see a degradation of the signal shape related to the low-pass compartment of the sensor. The high frequency components of the square wave are attenuated which prevents perfectly reconstructing of the original spectrum.

The transient impulse response (Yag laser) for different film thicknesses (0.4 μm and 0.8 μm) and materials (Au, Cr and W) show that rise times vary from 10 to 12 μs for the six different configurations. The lowest rise times are obtained with the gold and the highest ones for the chromium regardless of the deposition thickness (Fig. 6a). The results show rise times of 11 μs for all of probes (with different temperature levels) and decrease times ranging from 80 to 500 μs (Fig. 6b). As we have seen before, the microthermocouple made from a deposited golden junction of 0.4 μm remains the fastest probe.

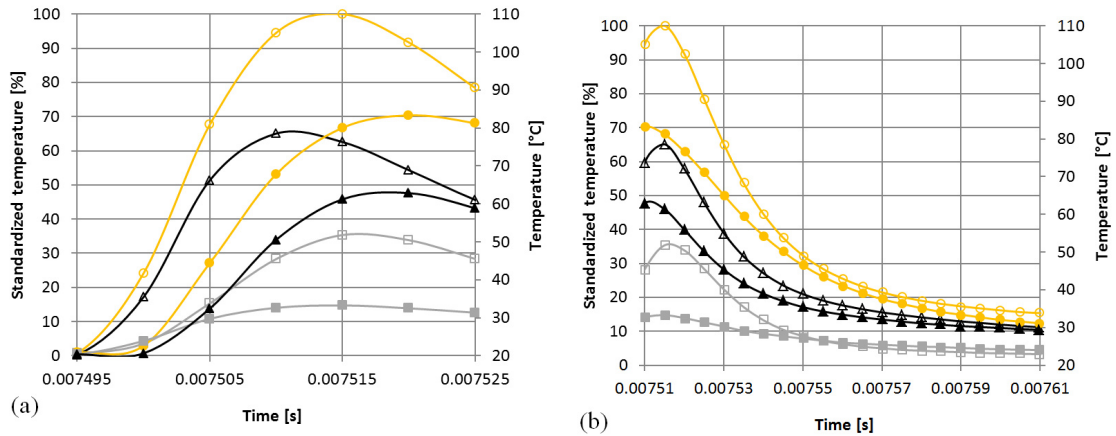


Fig. 6. Transient impulse response (Yag laser) for different film thicknesses (0.4 μm and 0.8 μm) and materials
(a) Heating phase (b) Relaxation phase

4. Conclusion

This paper describes the dynamic characterization of transient surface thermocouples. These sensors are made with Chromel-Alumel wires and the hot junction is obtained by a metallic deposit. The configurations tested correspond to 0.4 and 0.8 μm deposit thickness made of gold, chromium or tungsten. Several parameters can be used to characterize a sensor as its time constant, response time, the rising and decreasing times or the cut-off frequency. Given the fact that there are independent of the order of the studied system, only the last three parameters have been considered in our measurements. The best results are obtained in the case of a radiative excitation (Yag laser) with deposited probes with gold junction of 0.4 μm thickness. The rise-time and decrease time are equal to 10 μs and 80 μs respectively and the cut-off frequency is equal to 67 Hz. The probes response is not equivalent to a first-order system but it remains difficult to determine it because the entire probe reacts finally as a multilayer system. However, the announced cut-off frequencies refer to the entire probe (junction, substrate and connector) and not to the layer which allows us the possibility to study unsteady thermal phenomena with relatively fast temperature variations.

References

- [1] Y. Heichal, S. Chandra, E. Bordatchev, A fast-response thin film thermocouple to measure rapid surface temperature changes, *Exp. Therm. and Fluid Science*, 30, (2005) 153-159.
- [2] M.A. Marr, J.S. Wallace, S.C., Larry Pershin, J. Mostaghimi, A fast response thermocouple for internal combustion engine surface temperature, *Measurements, Exp. Therm. and Fluid Science*, 34, (2010) 183-189.
- [3] H. Choi, X. Li, Fabrication and application of micro thin film thermocouples for transient temperature measurement in nanosecond pulsed laser micromachining of Nickel, *Sensors and Actuators A*, 136, (2007) 118-124.
- [4] M. Y. Doghmane, Phénomènes d'interaction fluide/paroi en écoulement instationnaire avec transfert de chaleur, PhD Thesis, Université de Franche-Comté, 2014.